Online available since 2007/Sep/15 at www.scientific.net
© (2007) Trans Tech Publications, Switzerland
doi:10.4028/www.scientific.net/KEM.348-349.121

Aspects of the modeling of high-cycle fatigue

Błażej Paluszyński[1,a], Thomas Böhlke[1,b]

[1]Institute of Engineering Mechanics, University of Karlsruhe (TH), Postfach 6980, D-76128 Karlsruhe, Germany

[a]paluszynski@itm.uni-karlsruhe.de, [b]boehlke@itm.uni-karlsruhe.de

Keywords: high-cycle fatigue, continuum damage mechanics, damage accumulation

Abstract. An overview on modeling of high-cycle fatigue is given and experimental findings of the damage accumulation are discussed. Finally we sketch an isotropic constitutive model for the description of the damage accumulation due to high-cycle fatigue.

Experimental Characteristics of Fatigue

The fatigue of materials has been studied since the end of nineteenth century, when August Wöhler, a German engineer, performed a systematic study on fatigue failures of railway axle. Since then many characteristics and mechanisms of fatigue have been recognized and documented. It was found that the fatigue process could be divided into two stages. Firstly, microstructural changes on the micro scale occur, the density of dislocations grows and microcracks initiate. Secondly, the microcracks coalesce and grow to create one or more macrocracks, which induce the final fracture. In case of high-cycle fatigue the first stage is the dominant one and takes the majority of the life-time (see Fig. 1).

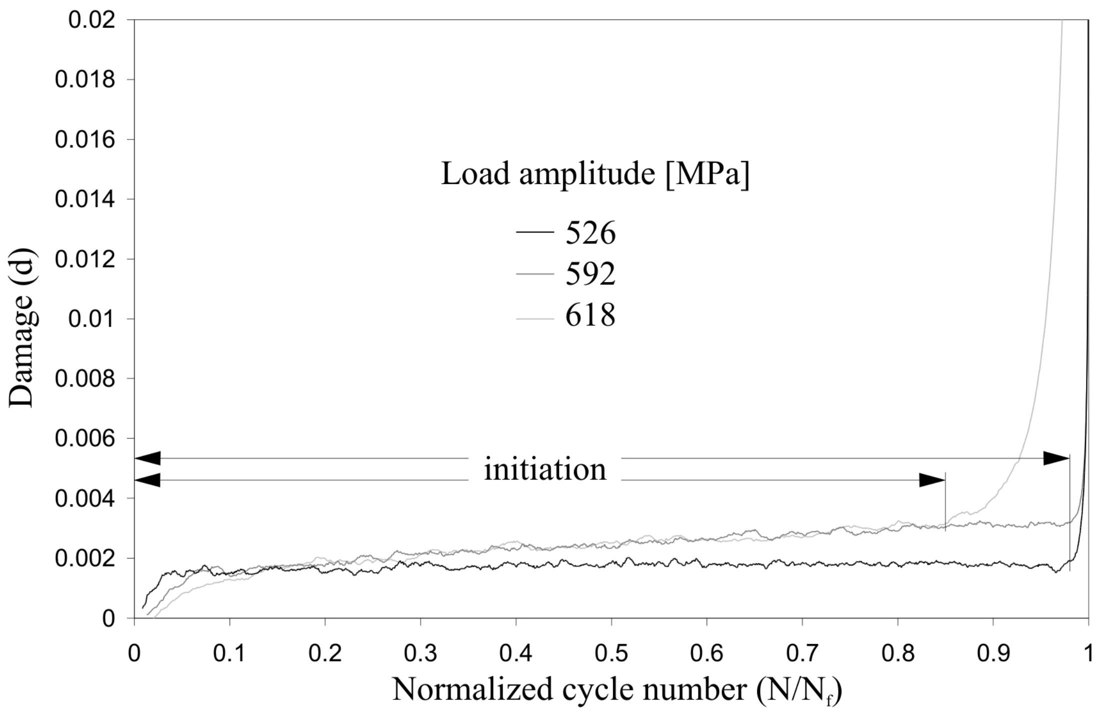

Fig. 1 *Examples of damage evolution by fatigue test on 30CrNiMo8 steel*

Important facts about fatigue are the *non-linear character* of the damage accumulation process and the *influence of the loading history* on it, which means that the same loading cycle can cause different damage to the material, depending on all preceding loadings. Furthermore, the *mean stress* *level* is of significant importance, since in most materials the damage increases faster under tension than under compression [1,2]. Another experimentally observed feature of high-cycle fatigue is the *decrease of the endurance limit* during the damage process. It has been observed that the endurance limit of a previously overstressed material is lower than the one of not-overstressed material [3]. The high-cycle fatigue process is influenced by many other factors, which are often of a random character. Examples are the micro structure of the material, the surface quality, the environmental temperature and humidity. Because of this complexity, experimental data show a large scattering. Therefore, in order to put the modeling on a sound basis a large number of experiments has to be considered and a statistical analysis has to be performed.

Experimental Results

To gain a better knowledge and understanding of high-cycle fatigue, a series of stress-driven tension-compression tests have been performed on 30CrNiMo8 steel according to ISO-standards [4]. The range of stress amplitude was 475 – 630 [MPa]. Beside the standard results for S-N curve, the damage accumulation in each test was calculated. It has been observed that the strain amplitude was increasing with cycle numbers (cyclic softening). The stiffness moduli was then calculated for each cycle and used as an indirect measure of material damage [5,6]:

$$d = 1 - \frac{\widetilde{E}}{E_0}$$

where d is the damage parameter, $\widetilde{E}$ - the measured stiffness and E_0 - the stiffness of material in virgin state. An example of such results is shown in Fig. 2.

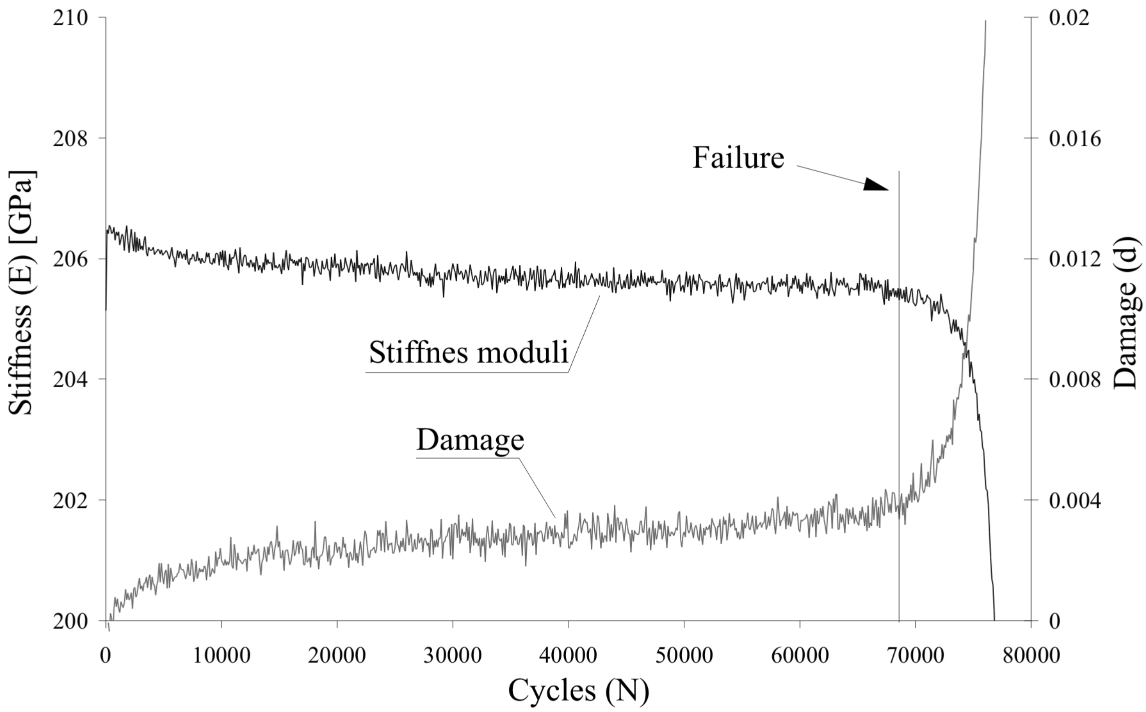

Fig. 2 *Evolution of the stiffness and the damage parameter during fatigue test of 30CrNiMo8 steel specimen at 618 [MPa] stress amplitude*

Based on the aforementioned damage measure, it can be observed that for the majority of the life-time the damage grows very slowly. However, prior to the complete fracture of the specimen damage starts to increase very rapidly. This is the phase where the macrocrack(s) propagate. In our consideration, this change of damage development is assumed to be the failure of the specimen. The experimental data indicate that the amount of damage at failure is very small and that it depends on loading amplitude (see Fig. 3).

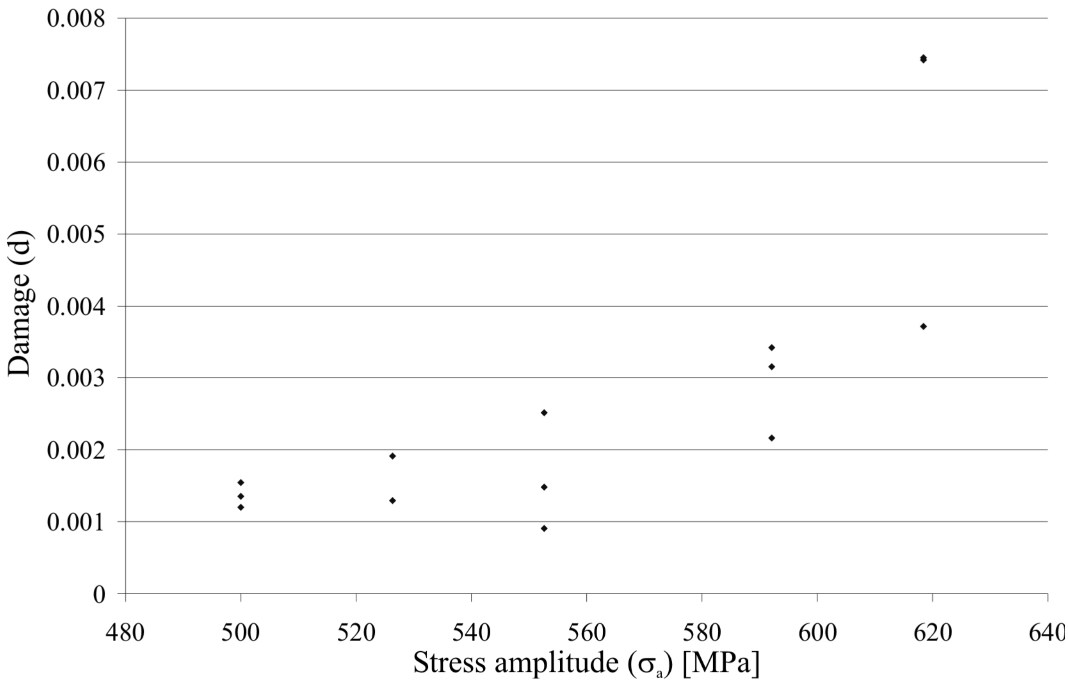

Fig. 3 *Damage at failure vs. loading amplitude*

Damage Model based on Continuum Damage Mechanics

Damage phenomena have been modeled for a long time and many different concepts exist. A detailed survey on theories and models for fatigue life prediction can be found in [7]. In the present work, the framework of *Continuum Damage Mechanics (CDM)* is used. The original idea of CDM was developed by Kachanov [8] and successfully applied to problems like: creep damage, ductile plastic damage or brittle fracture and as well as fatigue [9]. In our approach we develop

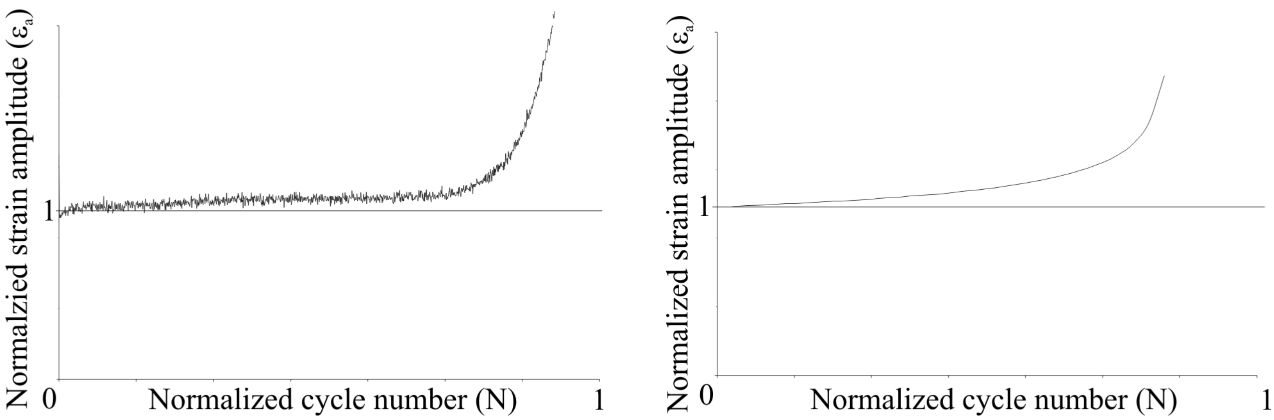

Fig. 4. *Qualitative change of the strain amplitude by fatigue test with constant stress amplitude: left - experimental, right - numerical*

an isotropic and thermodynamically consistent material model for the description of high-cycle fatigue, which is based on the concept of internal variables. The model is an extension of an earlier version [10] where the power law is used for the description of damage. Now it can predict the damage accumulation by loadings with varying amplitude and account for the influence of the loading history. The modification concerns the evolution equation of the damage parameter, which is assumed to be rate-independent. The preliminary numerical results show the capability of the model to reconstruct the experimental observation discussed above (see Fig. 4). The model has to be further developed in order to account for the decrease of the endurance limit during the damage process. Additionally, the influence of the mean stress has to be implemented in the model.

Summary

Observations show fatigue to be a complex phenomenon. The main features of high-cycle fatigue like: cycle softening, non-linearity of damage accumulation and influence of the loading history, can be captured by the developed model. Further enhancements and experimental investigations are subjects of the current work in order to improve the accuracy and reliability of the model.

References

[1] T. Łagoda, E. Macha and R. Pawliczek: *The influence of the mean stress on fatigue life of 10HNAP steel under random loading*, Int. J Fatigue Vol. 23 No. 4 (2001), p. 283–291

[2] L. Susmel, R. Tovo and P. Lazzarin: *The mean stress effect on the high-cycle fatigue strength from a multiaxial fatigue point of view*, Int. J Fatigue Vol. 27 No. 8 (2005), p. 928–943

[3] H. Mayer, C. Ede and J.E. Allison: *Influence of cyclic loads below endurance limit or threshold stress intensity on fatigue damage in cast aluminium alloy 319-T7*, Int. J Fatigue Vol. 27 No. 2 (2005), p. 129–141

[4] ISO 12106 *Metallic Materials - Fatigue Testing - Axial-Strain-Controlled Method*

[5] L. Yang and A. Fatemi: *Cumulative Fatigue Damage Mechanisms and Quantifying Parameters: A Literature Review,* J. Testing and Evaluation Vol. 26 No. 2 (1998), p. 89-100

[6] J. Lemaitre and J. Dufailly: *Damage measurements*, Engineering Fracture Mechanics Vol. 28 No. 5-6 (1987) p. 643-661

[7] A. Fatemi and L. Yang: *Cumulative fatigue damage and life prediction theories: a survey of the state of the art for homogeneous materials*, Int. J Fatigue Vol. 20. No. I (1998), p. 9-34

[8] L.M. Kachanov: *Time to the rupture process under creep conditions*, Izvestiia AN SSSR OTN(8) (1984), p. 26-31.

[9] J. Lemaitre: *Engineering Damage Mechanics* (Springer, Berlin 2005)

[10] B. Paluszyński and E. Schnack: *Isotropic softening model for high-cycle fatigue*, PAMM Vol. 6, (2006), p. 187–188

Advances in Fracture and Damage Mechanics VI
doi:10.4028/www.scientific.net/KEM.348-349

Aspects of the Modeling of High-Cycle Fatigue
doi:10.4028/www.scientific.net/KEM.348-349.121